

# Stream Ecosystem Responses to the 1988 Wildfires



by G. Wayne Minshall, Christopher T. Robinson, and Todd V. Royer

The 1988 wildfires in the Greater Yellowstone Area (GYA) provided an important opportunity to assess the effects of large scale disturbance on stream ecosystems over time. Research conducted by the Stream Ecology Center of Idaho State University has documented these changes and their effects on stream biota during the last nine years. We examined environmental and biological responses of 20 streams in Yellowstone National Park (Fig. 1) each year for the first five years following the extensive wildfires in 1988 and we studied a subset of these streams in 1994, 1995, and 1997. Our findings demonstrate an integral relationship over time between a stream and its catchment (drainage basin) following large-scale disturbances such as wildfire. However, individual streams varied considerably in their responses, depending on such things as size and local variations in precipitation, geology,

and topography, with major ecological changes occurring each year following the fires. We were especially amazed by the major physical changes in streams that occurred even between 1995 and 1997. Indeed, some streams in fire-“ravaged” watersheds such as parts of Cache Creek changed more in the last three years than in the first six post-fire years.

The changes with time and among streams were readily apparent in photographs taken from the same location and position each visit—a form of documentation called re-photography. The conditions were then documented by measurements of channel morphology, substratum particle-size distribution, and accumulations of woody debris. We expect that these changes in habitat conditions will be reflected in differences in the abundances and kinds of organisms found in the streams. Documenting these changes is important, as aquatic insects

are the “groceries” that the park’s trout consume for sustenance and growth.

## Our Working Hypotheses

Current theoretical constructs (ideas) for flowing water (lotic) ecosystems provide a rich framework from which to postulate ecosystem response to large scale disturbances such as forest fire. Paramount to such knowledge is recognition of (a) the integral association between stream ecosystem responses and terrestrial conditions of the surrounding watershed; (b) the crucial linkage between aquatic and terrestrial food bases and the trophic composition of the fauna in streams, and; (c) the importance of stream size as a modifier of land-water interactions.

Based on these fundamental principles of stream ecology, we developed three primary hypotheses:

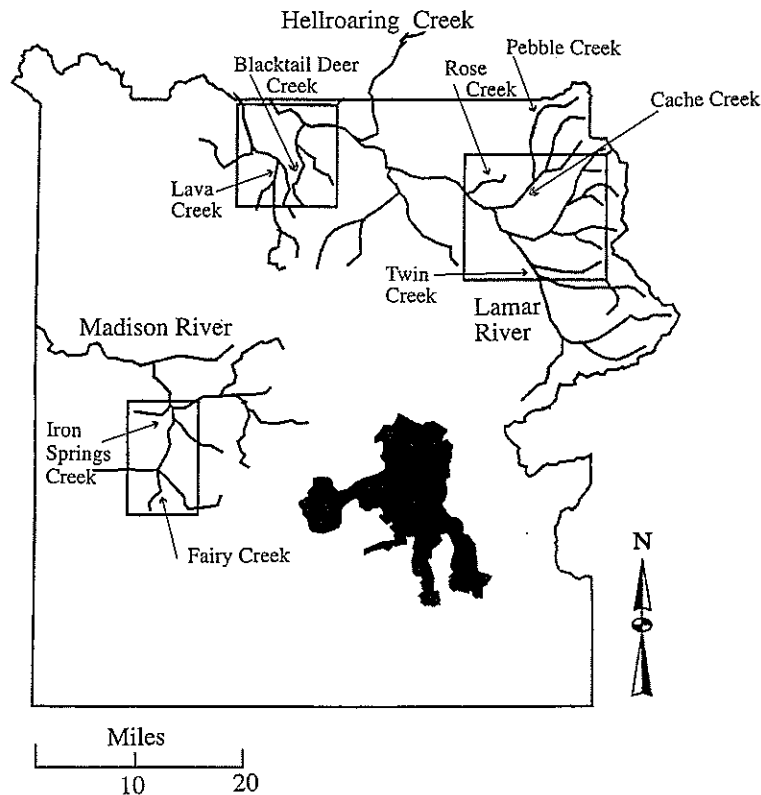


Figure 1. Location of the streams and major water bodies in the study. Rose, Pebble, and Amphitheater (to the right of Pebble) creeks are unburned (in  $\leq 5\%$  of catchment) reference streams; the remainder were burned (in  $\geq 50\%$  of the catchment) by wildfires in 1988.

1. Stream response will reflect changes in the structure and composition of adjacent terrestrial vegetation following wildfire. Since forest regeneration following wildfire is a long-term process, extending up to 300 years in the GYA, stream ecosystems were expected to respond similarly and to change progressively with temporal changes in plant community structure within a catchment.

2. Changes in environmental conditions will be reflected in the relative differences in amounts of food resources produced within (autochthonous) and outside (allochthonous) a stream and, in turn, the trophic composition of macroinvertebrate assemblages will reflect temporal changes in the food base among streams.

3. Major differences among streams, in terms of intensity of the effects of fire and recovery rates, will occur because of differences in stream size, watershed slope, and aspect. Watershed slope and aspect significantly influence the timing and rate of runoff and the type and amount

of riparian and upland vegetation.

More-specific hypotheses addressed major ecosystem components that were associated with the general points above. In addition, we predicted long-term alterations associated with the recovery of riparian and terrestrial vegetation, and consequent shifts of instream food resources and retention characteristics.

#### Chronology of Changes in Stream Conditions Following Wildfire

It was insightful to separate the temporal responses of streams to wildfire into four periods: (1) immediate changes (the time of active burning to a few days after); (2) short-term changes (from a few days to the end of the first year); (3) mid-term changes (the second year to sometime beyond the tenth year); and (4) long-term changes (from tens to hundreds of years). The precise length of each period depends on the degree of disturbance by fire and the environmental conditions of burned catchments such as weather and

climate, topography, geology, soil conditions, and forest type. The immediate and short-term effects were expected to be the most dramatic and to alter stream conditions profoundly, relative to those before the fires. The mid- and long-term changes in stream ecosystems were hypothesized to parallel the successional replacement of the terrestrial vegetation.

#### Immediate Effects

Beginning in late September of 1988, we examined the fire effects in 18 burned and 4 reference streams (one of each was eventually eliminated from consideration). Losses in upland and riparian vegetation and the almost instantaneous conversion of terrestrial vegetation to charcoal and ash resulted in immediate changes in the amount of light and quality of organic matter, i.e., food resources entering the streams. The most striking immediate changes within stream channels were the incineration and scorching of emergent mosses and heat fracturing (splaying) of rocks in and adjacent to smaller streams. Although most burned trees remained standing, many downed trees and large limbs were observed within and/or bridging streams. We also counted up to 10 dead cutthroat trout in our 250-m long study sections in mid-sized (3rd order) Cache Creek and the West Fork of Blacktail Deer Creek. These are believed to have died as a direct result of the fire (see below). However, we also know of another instance on a tributary to the Little Firehole River where an errant drop of fire-retardant was responsible for a number of fish deaths.

Most dissolved chemical measures increased in streams of burned catchments the first year following the fires. Based on studies by other researchers in 1988 on the effects of wildfire on Glacier National Park streams (Spencer and Hauer 1991), we believe dramatic and rapid increases in stream phosphorus and nitrogen levels occurred during the Yellowstone fires due to inputs from ash and smoke gases, respectively. We speculate that high ammonia levels that entered the water from the smoke were responsible for the observed fish mortalities. Few or no immediate deleterious effects of fire were evident in algae growing on

rocks (periphyton) or macroinvertebrate assemblages, even in the smallest streams observed. These impacts are more difficult to discern due to the small size and rapid decay rates of the organisms involved, although lotic macroinvertebrates are adversely affected by exposure to ammonia.

Our investigation revealed distinct differences in the effects of wildfire on streams of different size. Following fire, small headwater tributary streams (1st and 2nd order—e.g., Fairy Creek and the upper parts of Blacktail Deer Creek) were more physically and chemically variable than intermediate-size streams (3rd and 4th order—e.g., Cache and Hellroaring creeks) or reference streams. In general, smaller streams had a greater proportion of their catchments burned than larger streams. For our study streams, the mean catchment burned was 75 percent for 1st- and 2nd-order streams and 50 percent for 3rd- and 4th-order streams (Fig. 2). How-

ever, we observed during aerial and ground reconnaissance that the catchments of many fire-affected 3rd- and 4th-order streams throughout Yellowstone Park and along its northern boundary were less than 50 percent burned, and those of larger streams were even less burned. (No streams larger than 6th order are found in the park.) Consequently, the impact on biological properties also appeared more pronounced in smaller streams, although intermediate-size burned streams located in steep terrain with confined flood plains (e.g., 3rd-order Cache and Hellroaring creeks) experienced greater overland flow and associated effects on the biota than did other large study streams.

The most consistent outliers from the

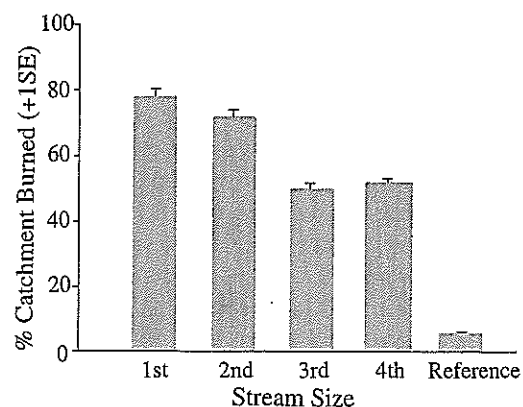
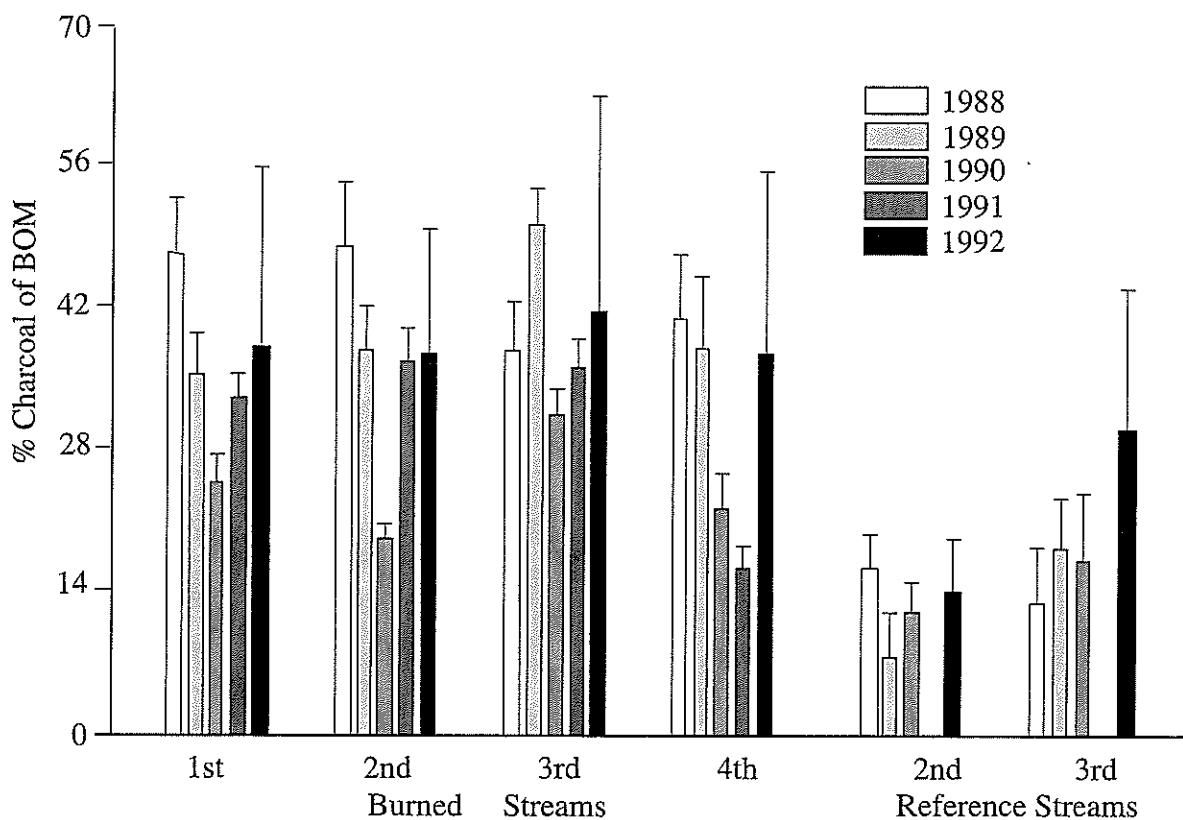


Figure 2. The percent catchment area burned by wildfires in 1998 for each of the four most abundant stream sizes and the reference sites used in this study.

general patterns found in this study Fairy and Iron Springs creeks, were attributable to one or more relatively unique features. These two streams were located along the west side of Yellowstone in an interior-type climate, characterized by a

Figure 3. The percent of benthic organic matter estimated as charcoal in streams of burned catchments and nearby reference streams following the 1988 fires.



spring peak in precipitation and Douglas-fir cover, and underlain by different base rock (rhyolite) than the other streams we examined, which are located in the north-eastern corner of the park on andesite rock in a montane-type climate characterized by Engelmann spruce cover. In addition, the 2nd-order site at Fairy Creek had the lowest gradient of any study stream and was unforested and strongly influenced by geothermal springs. A large proportion of flow in Iron Springs Creek is groundwater; thus this 3rd-order site displayed little variation in flow and usually did not freeze over in winter.

### Short-term Changes

From October 1988 to March 1989, macroinvertebrate abundance and richness decreased in 6 of 8 sampled burned sites, whereas these values increased or remained constant in reference streams. Because rainfall was minor and then the ground became frozen and snow-covered and the streams ice-covered for most of the time, no physical disturbances from runoff occurred during this period. Therefore, we attribute these changes to high amounts of charcoal (>40 percent) in stream benthos as a result of the fires (Fig. 3) and the absence of unburned organic matter and algae. We had expected that burned materials would be the principal source of allochthonous organic matter at this time; however, we had not anticipated that ice and snow cover would reduce the amount of light reaching the streambed and severely limit the growth of attached algae.

We believe that the input of charcoal decreased the palatability and quality (e.g., increased carbon:nitrogen values) of organic matter resources as food. For example, in a food utilization study of some selected stream invertebrates, only 1 taxon of 11 examined could exploit burned organic matter as a food source (Mihuc and Minshall 1995). Periphyton biomass also decreased in burned streams (except Iron Springs Creek) during this period, although comparable changes were observed in reference streams. Data since 1989 indicate charcoal is still being added to burned streams, but in reduced amounts. After 1990, most fire-related effects appear to be caused by physical disturbance

of the streambed associated with higher peaks in runoff rather than by changes in food resources.

Spring melting of the 1989 snow pack was much slower than anticipated (P. Farnes, Snowcap Hydrology, Bozeman, Montana, pers. commun.). Consequently, although several periods of "blackwater" associated with overland flow from heavy rains occurred between spring runoff and our August 1989 sampling, streambed erosion and channel alterations generally were much less than expected or than occurred in later years. However, several 1st- through 3rd-order streams, particularly Cache Creek and Hellroaring Creek catchments, did show substantial channel alteration and rearrangement of woody debris. In addition, reductions in flow and substrate heterogeneity were observed in burned streams, as indicated by changes in annual coefficients of variation for these measures between 1988 and 1990. No comparable changes in either velocity or substratum occurred in the reference streams. A number of studies in other areas of the West have documented similar changes in burned streams resulting from increased sediment loads and peaks in runoff.

Most dissolved constituents, especially nitrates, were higher in August 1989 than in October 1988, apparently in response to rainstorms during or immediately prior to the summer 1989 sample collections. In contrast to other ions (e.g., phosphate) that displayed only immediate changes in concentrations, temporal changes in instream nitrate levels typically reflected

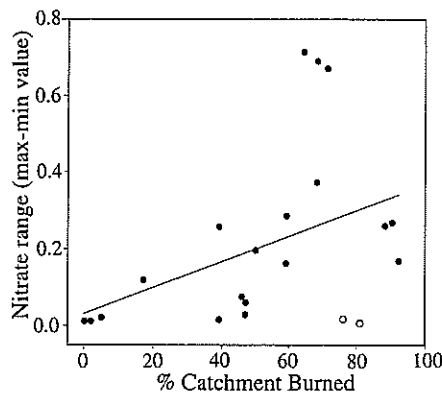
regrowth and reinvasion by adjacent terrestrial vegetation. Similarly, we found a direct correlation between nitrate loss and percent catchment burned in the Yellowstone study streams (Fig. 4). These findings are consistent with the well-known fact that vigorously growing plants actively sequester nutrients and delay or prevent their runoff into streams. Other changes in environmental conditions seen in the first year were the downstream movement of charcoal and fine sediment and increases in the temperature of burned headwater streams.

### Mid-term Changes in Post-fire Stream Systems

The mid-term responses (1990 to present) of Yellowstone stream ecosystems to wildfire were driven primarily by impacts from high runoff from snowmelt and localized rainstorms and by regrowth of terrestrial vegetation. Although some major effects of fire were evident in the first three post-fire years, the biota in the burned streams appeared to be on a "fast recovery track" (*sensu* Minshall and Brock 1991), aided by relatively little change in channel morphology and progressive regrowth of the riparian vegetation. However, 1991 was marked by at least two large runoff events that caused major physical changes in all burned streams having moderate to steep gradients. Ewing (1997) also noted that suspended sediment loads in the Lamar River were elevated in 1991 in response to higher than average precipitation. All stream sizes examined (1st through 4th order) were affected but changes were most dramatic in 3rd-order streams (e.g., Cache Creek, Fig. 5). In Cache, disturbance of the channel expanded beyond the recent channel bounds (unvegetated by shrubs) to encompass the entire width of the historically active channel. The existing pre-fire channel was obliterated and the historic channel was leveled from bank to bank by a combination of scour and fill events.

Additional channel modifications were observed in 1992, especially in the Cache Creek headwater (1st and 2nd order) tributaries. In Cache Creek, headwater stream channel morphology changed only moderately during the rest of the period (1993-

Figure 4. Nitrate levels in stream water versus the percent of the respective catchment burned.



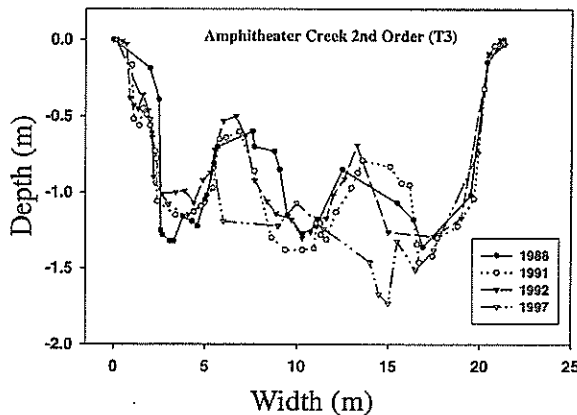
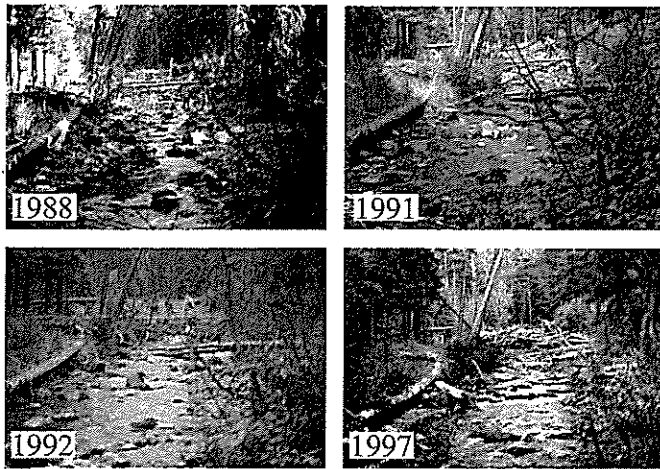
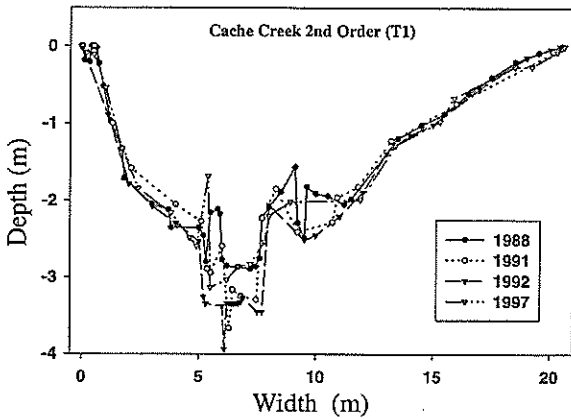
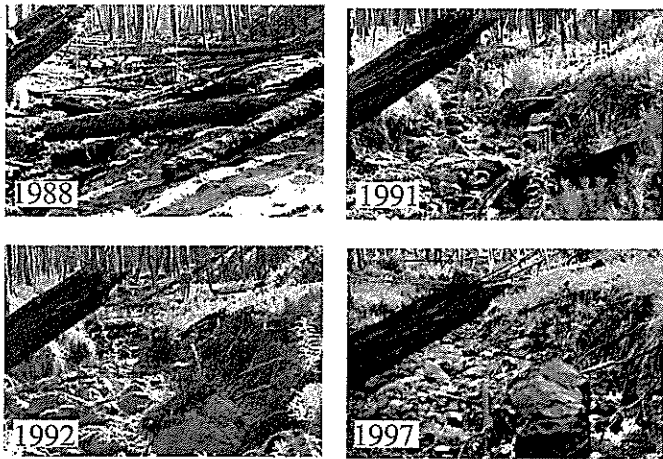


Figure 5. Comparison of photography and channel cross-section profiles of a stream in a burned catchment (upper: Cache Creek, a 2nd-order site) relative to one in an unburned catchment (lower: Amphitheater Creek) during the nine years of study.

1997). However, in many places along these streams, the flow tended to move back and forth across the valley floor in a temporally braided fashion, as deposition and erosion created new flow paths. In 3rd-order Cache, in all years during this period except 1994, dramatic changes in channel conditions were seen at most or all transects. In 4th-order Cache, year-to-year changes in channel form and substratum conditions were relatively minor until 1997, when a wave of cobblestones entered the section and the thalweg (an imaginary line that runs the length of the channel and stays in the deepest part of the channel) shifted from the left side of the bankful channel to the right side. In general, each of these major disturbances was reflected in declines in biotic properties and served as important "resets" or delays in lotic ecosystem recovery. Thus, in overview, major alterations in the stream channels and (by inference) the biotic community appeared to move progressively downstream over time, from the headwater tributaries in 1989, 1991, and 1992; to Cache 3<sup>o</sup> between 1991 and 1997; and, finally, to Cache 4<sup>o</sup> in 1997.

Our results thus far show the importance of stream discharge and gradient in mediating physical disturbances associated with adverse intermediate effects (e.g., channel scouring and sediment loading) resulting from wildfire. High-gradient streams responded sooner (i.e., at lower flows) than did low-gradient streams. At comparable discharges, high-gradient streams underwent greater physical disturbance than did similar-sized low-gradient streams. For instance, high-gradient burned streams displayed major changes (cutting or filling) in channel cross-section morphology in 1991 and 1992, whereas channel morphology of low-gradient burned streams and reference streams remained relatively constant (Fig. 6).

Data on substrata embeddedness suggest that a pulse of fine sediments moved from burned watersheds into headwater streams and then gradually into larger burn streams during the first five years. Median substrate size also decreased in 1st- through 3rd-order burn streams following 1988 and remained low through 1992. An unexpected finding from our study was the maintenance of large

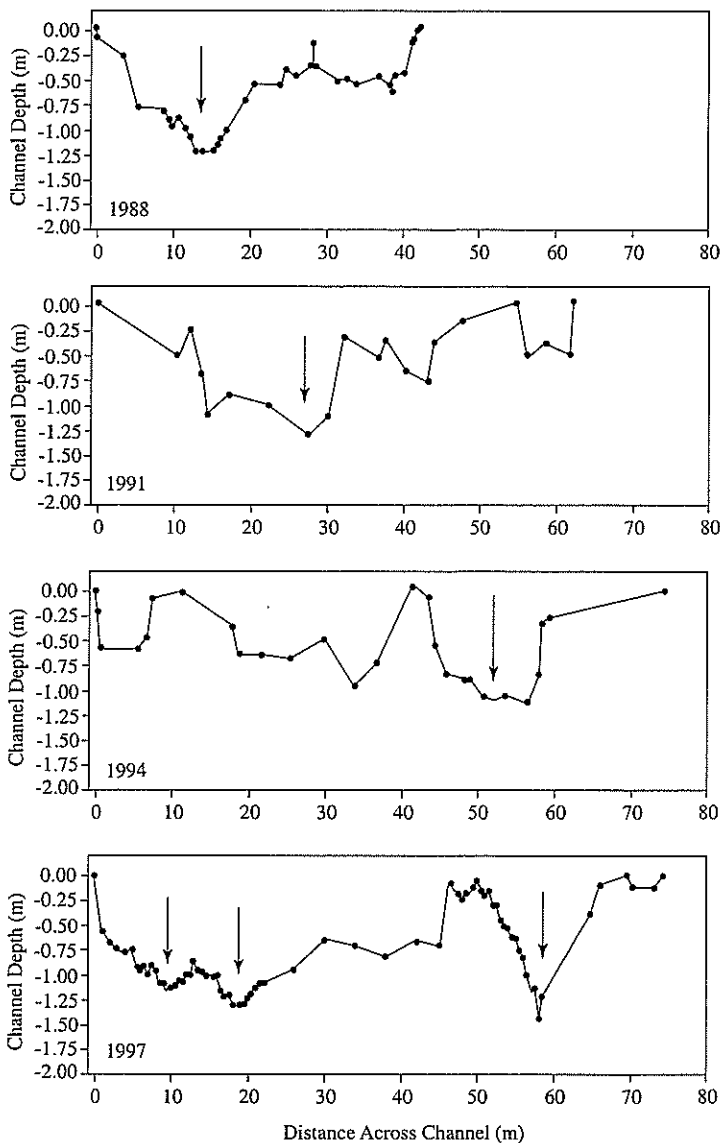


Figure 6. Cross-sectional profiles of the Cache Creek 3rd-order site for four selected years of substantial change at one (t-4) of five permanent transects established in 1988. Arrows denote locations of flowing water within the channel under baseflow conditions. Note the shifting and widening of the main channel after 1988.

amounts of fine inorganic sediments in headwater burn streams during the first five years. We expected these materials to be rapidly removed and then increase again after 5 to 10 years. Because Yellowstone streams have lost a considerable amount of retentive capacity due to steepening of the hydraulic gradient, straightening of the channel, and loss of large woody debris as a result of increases in peak discharge following the fire, we believe the "maintenance" of silt and sand resulted from continued input from the surrounding catchments. This

continued input also is suggested by an increase in percent charcoal of the organic matter deposited on the bottoms of streams in 1992. Although the remaining embeddedness data have yet to be analyzed, our qualitative impression is that most of the fine materials had been flushed from the system by year 5, after which their influence was overshadowed by bed-load movement of pebbles, cobbles, and boulders from 1993 to 1997.

Woody debris in streams retains organic matter and sediment and provides valuable habitat for fish and

macroinvertebrates. Within the burned catchments, woody debris came and went in all of the streams throughout the mid-term time interval. Initially, the 1st through 3rd-order burn streams contained more large wood pieces than did 4th-order burn streams. This can be attributed to the lower competency of high flows to move larger pieces of wood and to the closer proximity of trees to the main channel in smaller streams. The higher volume of the snow-melt flows in larger streams moved even the largest pieces of wood (including whole trees), leaving few pieces to stabilize the low-flow channel for longer than a year. However, later in the period (1995 to 1997), discharges were sufficiently high in the 3rd-order streams to cause them to converge with the 4th-order sites in terms of low abundance of large woody debris.

But the high flows in the years 1995 to 1997 undercut banks and felled many snags into the 3rd- and 4th-order stream channels. These collected on point bars, at the heads of islands, and in the shallows of braided sections, where the longevity of the large woody debris may extend beyond a year. Small streams had lower debris volumes because a large portion of fallen trees remained outside the channel margin. Other researchers have found an inverse relationship between stored organic matter and stream size, where 1st-order streams contained 75 percent and 3rd-order streams held only 20 percent of the organic matter in the stream channel. Although we did not find this response to hold initially, this did eventually occur in our study streams, due to much higher export of wood from the 3rd- and 4th-order streams. We not only found an increase in woody debris loading in all stream sizes immediately following catchment fire, but we expect that many of the standing fire-killed snags will fall and enter the channels over the next 10 years. Significant rearrangement of pre-fire, fire-felled, and newly-contributed woody debris in channels is still taking place.

As noted earlier, stream ecosystems are profoundly influenced by the condition of their watershed. We were struck by the fact that, many of the conifer seedlings that germinated in the year following the fires were 6 feet or more in

height by 1997 (Fig. 7). We also observed that many of the charred tree trunks of whole forests killed by the fire were still standing (Fig. 8). In another 10 years, it is expected that these “seedlings” will be 18 to 20 feet tall and that almost all of the dead snags will be down. These changes, occurring over a relatively short time, will dramatically alter the kinds and amounts of food resources in streams and change the availability of large woody debris. The changes that have taken place over the past nine years and are likely to occur over the next decade are expected to be the most dramatic to occur over the postulated 100- to 300-year recovery sequence.

### Predicted Long-term Changes

Based on our short- and mid-term results, long-term predictions for stream habitat development can be made for streams in burned catchments. Nearly all headwater streams are accruing pieces of wood. These are important in the formation of pool habitat in steep-gradient streams. As wood stabilizes, longer-lasting pools are expected to form which should increase habitat for fish. However, because less wood was found in the larger (3rd- and 4th-order) burned sites toward the end of the first 10 years, we anticipate fewer pools will form in fire-affected larger streams than in corresponding reference streams. In turn, a decrease in adult fish density should accompany habitat development. Large trees should again enter stream channels, forming deep pools and maximizing fish habitat, about 150 years following the fires. However, habitat diversity also should decrease in the streams as the forests in their catchments reach full development (climax).

Macroinvertebrate communities in burned sites displayed major changes in response to the observed changes in instream habitats. For example, burned sites exhibited differences in trophic group composition from that found in reference streams, suggesting alterations in food resources and a shift to more trophic generalists. However, macroinvertebrate response appeared to be more individualistic rather than associated with community properties such as species richness



Figure 7. Photograph showing the height of seedlings in 1995, indicating the extent of recovery of the trees that will replace the snags when they fall.

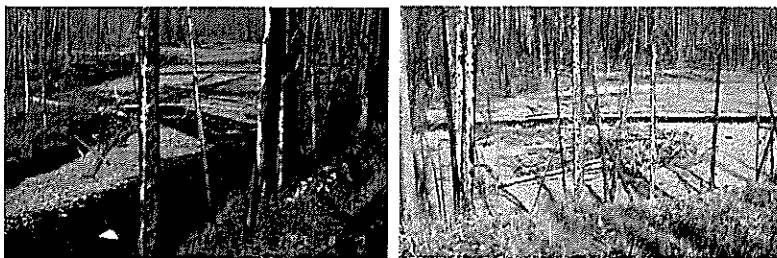


Figure 8. Two photos showing that many of the dead snags are still standing. All photos this article courtesy the authors.

and diversity. These properties showed substantial recovery within the first year following the wildfires, whereas assemblage composition displayed significant changes that were apparent even in post-fire year 9.

The changes wrought by fire can affect macroinvertebrates in ways other than through alterations in food resources, such as via higher water temperatures. Individual life histories and life styles respond in different ways and in different degrees to these various changes. Opportunistic species, particularly those well-suited for dispersal through drift and with relatively short generation times (such as chironomids and *Baetis*), seem to be especially adapted to conditions following fire, regardless of their trophic niche. In contrast, other species decreased in abundance soon after the fire and showed little or no recovery during the study. This was particularly noticeable among the Ephemeroptera, especially the dorso-ven-

trally compressed taxa (e.g., *Cinygmula*, *Epeorus*, and *Rhithrogena*).

Our results emphasize the importance of studying stream ecosystems for many years following large-scale disturbance. Conclusions based on only one or a few years of data can be misleading in terms of overall trends, as evidenced by the apparent “devastation” of stream ecosystems immediately after the 1988 fires, their rapid progress toward “recovery” in post-fire years 1 and 2, their equally abrupt downturn in post-fire years 3 and 4, and their massive reorganization in years 7 to 9 (Fig. 5). Far too little data exist on conditions for extended periods after fire to know for certain whether our predictions for Yellowstone will prove correct. In fact, the initial recovery trajectory seen for Yellowstone streams is much different—faster initially, with longer time delays before major storm impacts were seen—than expected, based on research we have done in central Idaho. The ab-

sence of comparable data on long-term effects, high year-to-year variability in post-fire disturbance impacts among streams of different size, and differences in recovery trajectories from those found in other Rocky Mountain streams provide strong arguments for obtaining an extended temporal perspective for Yellowstone lotic ecosystems in the aftermath of the 1988 fires. \*

*Dr. G. Wayne Minshall is professor of ecology in the Department of Biological Sciences at Idaho State University in Pocatello. He has studied the effects of wildfire on streams for nearly 20 years and initiated research on Yellowstone National Park streams while the fires were still raging. Dr. Christopher Robinson is currently a research scientist in the Swiss Federal Institute for Environmental Science and Technology in Duebendorf. He received his doctorate from Idaho State University in 1992 and remained there as a postdoctoral research associate into 1995. During that period he collaborated closely with Dr. Minshall on their Yellowstone fire study and had major responsibility for the completion of the first five years of the project. Todd Royer is a Ph.D. candidate at Idaho State University, where he received his master's degree in 1995. He has been involved with the project since 1992.*

#### REFERENCES

- Ewing, R. 1997. Suspended sediment in the rivers of Northern Yellowstone. *Yellowstone Science* 5(1): 2-7.
- Mihuc, T. B. and G. W. Minshall. 1995. Trophic generalists vs. trophic specialists: implications for food web dynamics in post-fire streams. *Ecology* 76:2361-2372.
- Minshall, G. W. and J. T. Brock. 1991. Observed and anticipated effects of forest fire on Yellowstone stream ecosystems. Pages 146-157 in R. B. Keiter and M.S. Boyce, eds. *The Greater Yellowstone Ecosystem: Balancing Man and Nature on America's Wildlands*. Yale University Press, New Haven, Conn.
- Minshall, G. W., J. T. Brock, and J. D. Varley. 1989. Wildfires and Yellowstone's stream ecosystems. *BioScience* 39:707-715.
- Minshall, G. W., C. T. Robinson, and D. E. Lawrence. 1997. Immediate and mid-term responses of lotic ecosystems in Yellowstone National Park, U.S.A. to wildfire. *Canadian Journal Fisheries and Aquatic Sciences* 59:2509-2525.
- Minshall, G. W., C. T. Robinson, T. V. Royer, and S. R. Rushforth. 1995. Benthic community structure in two adjacent streams in Yellowstone National Park five years after the 1988 wildfires. *Great Basin Naturalist* 55:193-200.
- Spencer, C. N., and F. R. Hauer. 1991. Phosphorus and nitrogen dynamics in streams *Benthological Society* 10:24-30.

## PLEASE KEEP US COMING

Send your tax deductible donation in support of  
*Yellowstone Science* to:

Yellowstone Association  
P.O. Box 117 - *Yellowstone Science*  
Yellowstone National Park, WY 82190

*We wish to thank all of you who have so generously contributed in the past,  
and hope that you will continue to do so in the future.*